The Economics of Natural Disasters – A Survey*

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Abstract

Catastrophes caused by natural disasters are by no means new, yet our evolving understanding regarding their relevance to economic development and growth is still at its infancy. In order to facilitate further necessary research on this topic, we summarize the state of the economic literature that examines the aggregate impact of disasters. We review the main disaster data sources available, discuss the determinants of the direct effects of disasters, and distinguish between the short‐ and long‐run indirect effects. After reviewing these literatures, we examine some of the relevant policy questions, and follow up with projections about the future likelihood of disasters, while paying particular attention to the projected climate change. We end by identifying several significant gaps in this literature.

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1. Introduction – why do we need this survey?

This week, the last week of September 2009, a tsunami in Samoa, two typhoons in the Philippines, an earthquake in Sumatra and a hurricane off Mexico's Pacific coast have caused untold damage and several thousand deaths. Catastrophes that are associated with natural phenomena are by no means new. Recent much larger events, such as the Indian Ocean tsunami of 2004, have been more heavily covered by the media than previously, yet our rapidly evolving understanding regarding their relevance to economic development and growth is still at its infancy.

Much research in both the social and especially the natural sciences has been devoted to increasing our ability to predict disasters and prepare for them. Interestingly, however, the economic research on natural disasters and their consequences is fairly limited. In order to facilitate further necessary research on this topic, we summarize here the state of this literature, and point to questions that we believe need further probing.

In two recent papers, Barro (2006 and 2009) has shown that the occurrence of infrequent economic disasters has much larger welfare costs than continuous economic fluctuations of less amplitude. Barro estimated that, for the typical advanced economy, the welfare cost associated with large economic disasters such as those experienced in the twentieth century (wars, economic depressions, financial crises) amounted to about 20 percent of annual GDP, while normal business cycle volatility only amounted to a still substantial 1.5 percent of GDP. For developing countries, which usually suffer from a larger propensity of natual disasters of all types, and of even larger magnitude than in advanced economies, these events have an even greater effect on the welfare of the average citizen.

Sen (1981), in his seminal economic history of famines, famously observed that: "Starvation is the characteristic of some people not *having* enough food to eat. It is not the characteristic of there *being* not enough food to eat" [italics in original]. In Sen's work, and in others' following, the central emphasis is that the costs associated with what we define as natural disasters are largely determined by economic forces rather than predetermined by natural processes.[3] Sen's observation suggests that economics is important not only in understanding what happens after a disaster occurs, but rather that the very occurrence of disasters is an economic event.

A recent pertinent example is the devastation that Hurricane Ike left in Haiti and Cuba in September 2008. Ike hit both islands with similar ferocity, though it made landfall over a larger and more populated area in Cuba (in Havana, while in Haiti it skirted the coast near Gonaïve). Nevertheless, the immediate impact of the disaster was very different, with 7 dead in Cuba, and several hundred dead in Haiti.[4] Clearly, these dissimilar outcomes originated from different policies, institutional arrangements and economic conditions. Maybe more obviously, had hurricane Ike passed over a deserted island it would not have been considered a natural disaster at all.

Skoufias, 2003, distinguishes between *ex-ante* mitigation and *ex-post* coping with natural disaster shocks. The literature on mitigation is quite large, even if it largely originates from disciplines other than economics. However, *ex-ante* mitigation clearly costs resources, and therefore a careful evaluation of the likely *ex-post* impacts and the probability of disasters

[3] In his 1981 book on famines, Sen calls these economic forces 'entitlement relations.'
[4] The BBC cites 7 dead in the two biggest September 2008 storms in Cuba and 793 in Haiti. http://news.bbc.co.uk/2/hi/americas/7652075.stm and http://news.bbc.co.uk/2/hi/in_depth/7619274.stm

occurring are necessary. Here, we focus on the *ex-post* of disasters, including both discussions of the actual costs of disasters and the coping strategies that can potentially be useful for policymakers to implement. An economic analysis of *ex-ante* mitigation can only take place after a good accounting of the *ex-post* is available.

Pelling et al. (2002) and ECLAC (2003) introduce a typology of disaster impacts that we adopt here. They distinguish between direct damages, and indirect damages. Direct damages are the damage to fixed assets, and capital (including inventories), damages to raw materials and extractable natural resources, and of course mortality and morbidity, that are a direct consequence of the natural phenomenon (i.e., an earthquake, a flood, a dry-spell, etc.).

Indirect damages relate to the economic activity, in particular production of goods and services, that will not take place following the disaster and because of it. These indirect damages may be caused by the direct damages to physical infrastructure, or because reconstruction pulls resources away from production. These indirect damages also include the additional costs that are incurred because of the need to use alternative and potentially inferior means of production and/or distribution for the provision of normal goods and services. At the household level, these indirect costs also include the loss of income resulting from the non-provision of goods and services or from the destruction of previously used means of production. These costs can be accounted for at the aggregate, by examining the overall performance of the economy, as measured through the most relevant macro economic variables; in particular gross domestic product, the fiscal accounts, consumption, investment, the balance of trade and the balance of payments. They can also be further divided, following the standard distinction in macroeconomics, between the short-run (up to several years) and the long-run (at least 5 years, but sometimes also measured in decades); we use this distinction in the discussion that follows.[5]

Section 2 starts by reviewing the main data sources used in this largely empirical literature. Section 3 discusses the determinants of the direct effects, while section 4 examines the short- and long-run indirect effects. Section 5 focuses on policy, while section 6 describes several case studies of specific disasters and the insights gained from them. Section 7 follows up with projections about the future likelihood of disasters, given the projected change in climatic conditions worldwide; section 8 summarizes and points to several significant gaps in this literature.

2. Data on Disasters

Almost all the empirical work we survey here relies on the publicly available Emergency Events Database (EM-DAT) maintained by the Center for Research on the Epidemiology of Disasters (CRED) at the Catholic University of Louvain, in Belgium (http://www.emdat.be/). The database is compiled from various sources, including UN agencies, non-governmental organizations, insurance companies, research institutions and press agencies.

EM-DAT defines a disaster as a natural situation or event which overwhelms local capacity, and/or necessitates a request for external assistance. For a disaster to be entered into the EM-DAT database at least one of the following criteria must be fulfilled: (1) 10 or more people reported killed; (2) 100 people reported affected; (3) declaration of a state of

[5] One can also account for disaster costs at the micro level (especially households). For example, see Dercon (2004), and Townsend (1994).

emergency; or (4) call for international assistance.[6] Disasters can be hydro-meteorological including floods, wave surges, storms, droughts, landslides and avalanches; geophysical - earthquakes, tsunamis and volcanic eruptions; and biological - covering epidemics and insect infestations (these are much more infrequent in this database).

The amount of damage reported in the database consists only of direct damages (e.g. damage to infrastructure, crops, housing). The data reports on the number of people killed, the number of people affected, and the dollar amount of direct damages in each disaster. An alternative but similar source that is less extensive, and only parts of which are publicly available, is the Munich Re dataset at: http://mrnathan.munichre.com/.[7]

A few papers use other data sources. Most notable are the papers who aim to estimate the impact of storms/hurricanes. These papers use data on storm intensity, typically measured by wind-speed or storm radius that is taken from the U.S. National Oceanic and Atmospheric Administration-NOAA (e.g., Yang, 2008) and the American Meteorological Society (e.g., Bluedorn, 2005).

Before reviewing the evidence on the impacts of natural disasters it is useful to describe the stylized facts. First, natural disasters, as defined in the EM-DAT database, are fairly common events, and their incidence has been growing over time. Figure 1a plots the average number of natural events (including hydro-meteorological and geophysical events) per country over the

[6] The number of people killed includes "persons confirmed as dead and persons missing and presumed dead"; people affected are those "requiring immediate assistance during a period of emergency, i.e. requiring basic survival needs such as food, water, shelter, sanitation and immediate medical assistance."

[7] A similar data collection effort with similar coverage but more limited access is maintained by another reinsurer, Swiss Re. These datasets are contrasted and reviewed by Tschoegl (2006).

span of the last four decades.[8] The figure shows that the incidence of disasters has been growing over time everywhere in the world. In the Asia-Pacific region for example, which is the region with the most events, the incidence has grown from an average of 11 events per country over the 1970's to over 28 events in the 2000's.[9] In other regions, while the increase is less dramatic, the trend is similar. However, these patterns appear to be driven to some extent by improved recording of milder events, rather than by an increase in the frequency of occurrence. Furthermore, truly large events –i.e., conceivably more catastrophic— are rarer. Both of these facts are shown is figure 1b, where the sample is restricted to large events only, and where "large" is defined in relation to the world mean of direct damage caused by natural events.[10] As it is evident from the figure, there is no time trend for the subset of large events in any region.[11] Moreover, the frequency of occurrence of "large" disasters is significantly smaller than for all events. For example, while there are more than 28 events per country on average in Asia-Pacific in the 2000's, the frequency of occurrence of large events is only 0.5 episodes per country. This suggests that there is a high incidence of small disasters in the sample or, more precisely, that the threshold for what constitutes a disaster (and hence gets recorded in the dataset) is quite lenient. It is important to keep this fact in mind when using this dataset as it should not be surprising that it is hard to find consistent results about

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[8] The figures are very similar when we disaggregate the incidence data by type of events, including biological events. We exclude the former from the reported figures as they are more rare events and the data appears to be less precise. However, the patterns described below do not change when we include biological events in the sample (figures available upon request).

[9] The numbers corresponding to the decade of 2000 were adjusted to account for the fact that there is one less year of reported data in this decade. In particular, in the 2000's only, each observation (i.e., average number of events per country in different regions) is multiplied by 10/9 to make them comparable to previous decades that have one additional year of data.

[10] A large disaster occurs when its incidence, measured in terms of people killed as a share of population, is greater than the world pooled mean for the entire sample period.

[11] This results change only in the case of Africa when we include biological events in the sample. The reason is that these events occur overwhelmingly in Africa, and their recording in the dataset is biased towards the latest years.

the economic impact of natural disasters when there is such a broad definition of what really constitutes an event.

The direct damages caused by natural disasters are also heterogeneous across countries, with a smaller effect in advanced economies, but a big variance in outcomes within regional country groupings. Figures 2-4 plot the distributions of fatalities (as a share of population), people affected (also as a share of the population) and direct economic damages (as a share of GDP) of natural events over the period 1970-2008 for six different regional groupings. Within each box, the center line corresponds to the median impact in the region, while the edges of the box are the p(75) and p(25) percentiles of the distribution and the lines outside the box correspond to the upper and lower adjacent values respectively.

The median impact of disasters, however measured, is typically smaller in Western Europe and North America (i.e., the most developed regions). For example, in terms of people killed, for events occurring in North America the median incidence is less than 0.1 person per million inhabitants, while for events in Africa or Latin America and the Caribbean, the corresponding number is over 1. Similar results are observed using the other outcome variables. However, the dispersion of outcomes is very large within regions suggesting that countries face different vulnerabilities even within the same geographical area.

The overwhelming majority of people affected and killed by natural disasters are coming from developing countries, particularly in the Asia-Pacific region. Figures 5 and 6 show that 96 percent of the people killed, and 99 percent of the people affected by natural disasters over the period 1970-2008 were either in Asia-Pacific, Latin America and the Caribbean or Africa, whereas the combined population share of these three regions is approximately 75 percent of the world population. Since the 1970's, a total of almost 3 million people were reportedly killed by natural disasters in the three most vulnerable regions.

Finally, of the three types of natural disasters considered, hydro-meteorological events are the ones that cause the highest number of affected people in all regions of the world (Figure 7) and the same is true of the number of people killed, with the only exception of Latin America and the Caribbean, where geological events are reportedly responsible for more fatalities (Figure 8).

In summary, natural events are frequent although "large" events –the ones would typically be considered catastrophic—are rarer. The direct costs associated with these events are large and developing countries bear the lion's share of the burden, both in terms of casualties as well as of direct economic damages.

3. Determinants of initial disaster costs

A spate of papers in the last several years has attempted to understand the determinants of the initial direct costs of disasters. When evaluating the determinants of disasters, most papers estimate a model of the form:

$$DIS_{it} = \alpha + \beta \mathbf{X}_{it} + \varepsilon_{it} . \qquad (1)$$

Where DIS_{it} is a measure of immediate impact of a disaster(s) at country *i* and time *t*; using measures of primary initial damage like mortality, morbidity or capital losses. $\mathbf{X}_{it}$ is a vector of control variables of interest with each paper distinguishing different independent variables; typically $\mathbf{X}_{it}$ will include a measure of the disaster magnitude (i.e., Richter scale for earthquakes or wind speed for hurricanes) and variables that capture the "vulnerability" of the country to disasters (i.e., the conditions which increase the susceptibility of a country to the impact of natural hazards). ε_{it} is an iid error term. Instead of estimating these panels, several papers aggregate the data across time and estimate cross sections of country observations. These papers estimate a version of

$$\overline{DIS}_i = \alpha + \beta \overline{\mathbf{X}}_i + \varepsilon_i \qquad (2)$$

where variables are averages across the estimated time period.

One of the conditions that may increase the susceptibility of a country to the impact of natural disasters is the level of economic development. In fact, as reported in the previous section, most of the human and economic damages caused by natural disasters were in developing countries. Kahn (2005) estimates a version of (1) and concludes that while richer countries do not experience fewer or less severe natural disasters, their death toll is substantially lower. In 1990, a poor country (per capita GDP<$2000) typically experienced 9.4 deaths per a million people while a richer country (per capita GDP>$14,000) would have had only 1.8 deaths. This difference is, most likely, due to more resources spent on prevention efforts and legal enforcement of mitigation rules (e.g., building codes). In particular, some of the policy interventions likely to ameliorate disaster impact including land-use planning, building codes and engineering interventions are rare in less developed countries (see, for example, Freeman et al., 2003, and Jaramillo 2009).

Notwithstanding this, Kellenberg and Mobarak (2008) suggest a more nuanced nonlinear relationship between economic development and vulnerability to natural disasters, with risk initially increasing with higher incomes as a result of changing behaviors; e.g., residents locating to more desirable but more dangerous sites near coasts and floodplains.

Sadowski and Sutter (2005) provide some confirmation for this view by examining U.S. hurricanes and the ways in which better preparedness leads to higher residential coastal concentrations (where the risk from hurricane-associated wave surges is higher).

Another condition that may affect the vulnerability to natural disasters is country size. Bigger economies are more diversified and capable of engineering the inter-sectoral and inter-regional transfers required to mitigate the economic impact of natural disasters. In addition, geographical location is a critical determinant of the physical vulnerability of certain countries or regions to different types of natural disasters. The small-island states of the Caribbean region, for example, are particularly vulnerable on both dimensions (Rasmussen, 2004 and Heger et al 2008). In contrast, even by their size alone, large developed countries can more easily absorb output shocks from natural disasters originating in certain regions of the country (Auffret, 2003).

Other papers focus on the political and institutional factors that affect disaster impact. A consistent finding of several studies is that better institutions –understood for instance as more stable democratic regimes or greater security of property rights—reduce disaster impact (i.e, Kahn, 2005; Skidmore and Toya, 2007 and Raschky, 2008). Anbarci et al. (2005) elaborate on the political economy of disaster prevention. They conclude that inequality is important as a determinant of prevention efforts: more unequal societies tend to have fewer resources spent on prevention as they are unable to resolve the collective action problem of implementing preventive and mitigating measures. In similar vein, Besley and Burgess (2002) observe that flood impacts in India are negatively correlated with newspaper distribution; when circulation is higher, politicians are more accountable and the government is more active in both preventing and mitigating the impacts of disasters. Eisensee and Strömberg (2007) reach similar conclusions regarding the response of U.S. disaster aid to media reports.

Healy and Malhotra (2009) add to this literature by identifying the lack of political accountability for elected public officials in the U.S. as a reason explaining these inefficient location decisions. Voters reward candidates for post-disaster aid but not for well-funded prevention. Thus, the public sector under-invests in preventing these catastrophic events, but readily spends on post disaster reconstruction and aid.

In summary, thinking of natural disasters as economic phenomena and not as purely exogenous events, has led researchers to seek to explain the fundamental structural determinants of the direct damages incurred from disasters. While the damage caused by disasters is naturally related to the physical intensity of the event (i.e., the severity of a storm or earthquake), the literature has identified a series of economic, social and political characteristics that also affect vulnerability. A by-product of this analysis, of course, is that these characteristics are therefore potentially amenable to policy action.

4. Cross-country studies of Indirect Impacts

A disaster's initial impact causes mortality, morbidity, and loss of physical infrastructure (residential housing, roads, telecommunication and electricity networks, and other infrastructure). However, these initial impacts are followed by consequent impacts on the economy (in terms of income, employment, sectoral composition of production, inflation, etc.). Macroeconomics generally distinguishes between the short-run (usually up to three years), and the long-run (anything beyond 5 years is typically considered long-run). In the following subsections we summarize the state of the literature on the indirect economic effects of natural disasters. We start by reviewing the literature that examines the short-run, continue with a review of long-run growth effects, and then proceed to discuss other macroeconomic or socio-economic effects.

4.1 Short-run growth effects

The first recent attempt to empirically describe the macroeconomic dynamics of natural disasters is Albala-Bertrand (1993). Information about this and other papers discussed below is summarized in table 1. In this seminal monograph, Albala-Bertrand develops an analytical model of disaster occurrence and reaction and collects data on a set of disaster events: 28 disasters in 26 countries during 1960-1979. Based on before-after statistical analysis, he finds that GDP increases (0.4%), inflation does not change, capital formation is higher, agricultural and construction output increase, the fiscal and trade deficits increase (the trade deficit sharply), reserves increase, but no discernible impact on the exchange rate is observed.

The more recent literature typically utilizes more robust econometric techniques. When evaluating the determinants of these consequent impacts of disasters in regression framework, most papers estimate a model of the form:

$$Y_{it} = \alpha + \beta \mathbf{X}_{it} + \gamma DIS_{it} + \varepsilon_{it} . \quad (3)$$

Where Y_{it} is the measured consequent impact of interest (e.g., per capita GDP). DIS_{it} is a measure of the disaster's immediate impact on country *i* and time *t*; it is sometimes a binary indicator of disaster occurrence and sometimes a measure of the disaster magnitude—either using physical criteria like wind-speed or earthquake magnitude or using measures of primary initial damage like mortality, morbidity or capital losses. $\mathbf{X}_{it}$ is a vector of control variables that affect Y_{it}, potentially also including $Y_{i,t-1}$, and ε_{it} is an error term.

In order to facilitate investigations into the interaction of the initial disaster impact with country specific conditions, equations such as:

$$Y_{it} = \alpha + \beta \mathbf{X}_{it} + \gamma DIS_{it} + \delta DIS_{it} \cdot \mathbf{V}_{it} + \vartheta \mathbf{V}_{it} + \varepsilon_{it} \qquad (4)$$

where the $\mathbf{V}_{it}$ variables are the hypothesized interactions of disaster impact with macroeconomic, institutional or even demographic or geographic characteristics. In these specifications, the coefficients of interest are typically γ and the vector δ.

Raddatz (2007) is one of the early papers that attempt to estimate the effect of external shocks on short-run output dynamics in developing countries. Using a Panel-VAR variant of equation (3), he analyses the contribution of various external/exogenous shocks, natural disasters among them, in explaining output fluctuations. He concludes that natural disasters have an adverse short-run impact on output dynamics.[12]

Noy (2009) estimates a version of equation (4), and in addition to the adverse short-run effect already described in Raddatz (2007), he describes some of the structural and institutional details that make this negative effect worse. In particular, Noy (2009) concludes that countries with a higher literacy rate, better institutions, higher per capita income, higher degree of openness to trade, higher levels of government spending, more foreign exchange reserves, and higher levels of domestic credit, but with less-open capital accounts are better able to withstand the initial disaster shock and prevent further spillovers. Subsequently, Raddatz

[12] Yet, Raddatz (2007) concludes that only a small fraction of the output volatility in a typical low income country is explained by external adverse shocks (which include disasters). He finds climatic disasters are associated with only a 2% of the output volatility found in a typical developing country.

(2009) uses similar methodology to his earlier paper but extends the investigation on the short and long run impact of various types of natural disasters on countries in different income groups; he concludes that smaller and poorer states are more vulnerable, especially to climatic events and that most of the output cost of climatic events occurs during the year of the disaster. He also finds that a country's level of external debt, which is frequently mentioned as a limit to its fiscal capacity to respond to disasters, has no relation to the output impact of any type of disaster. His evidence also suggests that, historically, aid flows have done little to attenuate the output consequences of climatic disasters.

Loayza et al. (2009) extend this analysis by applying panel GMM estimation methodology to:

$$Y_{its} = \alpha + \beta \mathbf{X}_{its} + \gamma DIS_{it}^{K} + \delta DIS_{it}^{K} \cdot \mathbf{V}_{its} + \vartheta \mathbf{V}_{its} + \varepsilon_{its} \qquad (5)$$

where Y_{its} the economic impact of interest in country *i*, time *t,* and sector *s,* and DIS_{it}^{K} denotes a disaster of type K (floods, storms, earthquakes, and droughts).[13] They find both different impacts for different types of disasters, and different impacts of the same disaster on different sectors. Maybe more importantly, they reconcile the Raddatz (2007 & 2009), Noy (2009), and more recently Hochrainer's (2009) adverse-impact findings with earlier conflicting work that occasionally finds positive growth impacts of disasters (Albala-Bertrand, 1993 and Skidmore and Toya, 2002). Loayza et al. (2009) note that while small disasters may, on average, have a positive impact (as a result of the reconstruction stimulus), large disasters always have severe negative consequences to the economy in their immediate aftermath.

[13] Fomby et al. (2009) conducts a similar investigation using panel VAR methodology.

Several papers pursue similar investigations as in equations (4) and (5) but instead of relying on cross country panels they rely on more detailed panels at the firm, county, region, or the state level. Strobl (2008) uses differences in hurricane impact on coastal counties in the U.S.; Noy and Vu (2009) uses provincial disaster data from Vietnam, and Rodriguez-Oreggia et al. (2009) uses municipal data from Mexico.

Rodriguez-Oreggia et al. (2009), and Mechler (2009) innovate by examining poverty and human development (HDI - the World Bank's Human Development index), and consumption, respectively, instead of the standard growth variables. The first paper shows a significant increase in poverty and decline in the HDI in disaster-affected municipalities in Mexico; poverty increases by 1.5-3.6 percentage points. The second paper finds a small decrease in household consumption for low income countries hit by disasters. Leiter et al. (2009) uses European firm level data to examine the impact of floods on the firms' capital stock, employment, and productivity. They find mixed results on the capital stock (depending on the percent of intangible assets), a positive short term impact on employment and a negative impact on productivity.

In summary, the emerging consensus in the literature is that natural disasters have, on average, a negative impact on short term economic growth. Yet, the channels that are responsible for this economic slowdown have not been described methodically, at all. An examination of these channels, of course, also necessitates an attempt to determine whether these effects are transitory or permanent.

4.2 Long-run growth effects

Skidmore and Toya (2002), Noy and Nualsri (2007), Jaramillo (2009) and Raddatz (2009) examine the long-run impact of natural disasters on growth (information on these papers is summarized in table 2). The former use the frequency of natural disasters for the 1960-1990 period for each country normalized by land size in a cross-sectional dataset while the latter use a panel of country—5-years observations as in the extensive literature that followed the work by Barro (1997). These papers investigate the long-run trends in contrast to the literature described in the previous section.

Intriguingly, Skidmore and Toya (2002) and Noy and Nualsri (2007) reach diametrically opposing conclusions with the former identifying expansionary and the latter contractionary disaster effects. More recently Jaramillo (2009) finds qualified support for the Noy and Nualsri (2007) conclusion. Also, Raddatz (2009), using cumulative impulse response functions of the growth of real GDP per capita to different type of natural disasters, finds that in the long run, per capita GDP is 0.6 percent lower as a result of a single climatic event, although over 90 percent of the output cost occurs during the year of the disaster. In Raddatz's (2009) work, geological disasters do not have a statistically significant output effect either in the short- or in the long-run.

Skidmore and Toya (2002) explain their somewhat counter-intuitive finding by suggesting that disaster may be speeding up the Schumpeterian 'creative destruction' process that is at the heart of the development of market-economies. Cuaresma et al. (2008) attempts to investigate this 'creative destruction' hypothesis empirically by closely examining the evolution of R&D from foreign origin and how it is affected by catastrophic risk. They, however, conclude that the ‘creative destruction’ dynamic most likely only occurs in countries with high income per capita. For developing countries, disaster occurrence is associated with less knowledge spillovers and reduction in the amount of new technology being introduced.

Like Cuaresma et al. (2008), Hallegatte and Dumas (2009), critically examine the ‘creative destruction’ hypothesis, though in a caliberated endogenous growth theoretical model. They conclude that disasters are never positive economic events; and find that large disasters that overwhelm the local reconstruction capacity actually lead to poverty traps.

When compared to the short-run research, the literature on the long-run effects of natural disasters is more scant and its results remain inconclusive. Part of the reason for the scarcity of research in this area is the difficulty in constructing appropriate counterfactuals: what would have happened to the path of GDP growth in the absence of natural disasters? This is still, in our view, a very promising area of research.

4.3 Other economic impacts

Almost all existing research focuses on domestic production (GDP) or on incomes; other impacts of disasters have been under-investigated. For example, when disasters are likely to generate significant inter-regional transfers or even international aid, a more precise accounting of their likely fiscal impact is necessary. Accurate estimates of the likely fiscal costs of a disaster are useful in enabling better cost-benefit evaluation of various mitigation programs. Another motivation to estimate the fiscal cost is to better enable governments to directly insure against disaster losses, indirectly insure through the issuance of catastrophic bonds (CAT bonds), or through precautionary savings.

On the expenditure side, publicly financed reconstruction costs may be very different than the original magnitude of destruction of capital that occurred. On the revenue side of the fiscal ledger, the impact of disasters on tax and other public revenue sources has also seldom been quantitatively examined. Using panel VAR methodology, Noy and Nualsri (2008) estimate the fiscal dynamics likely in an 'average' disaster; however, they acknowledge that the disasters' impacts on revenue and spending depend on the country-specific macroeconomic dynamics occurring following the disaster shock, and the unique structure of revenue sources (income taxes, consumption taxes, custom dues, etc.) and large expenditures.

Borensztein et al. (2009) utilize data from Belize to estimate in a calibrated model the likely fiscal insurance needs of a government; while Barnichon (2008) calculates the optimal amount of international reserves for a country facing external disaster shocks using a similar methodology.

Several other papers examine various other facets of disaster impact. For example, Neumayer and Plümper (2007) observe that women and girls are much more vulnerable to disasters, in terms of life expectancy, than men; with large disasters having an especially unequal effect. Evans et al. (2009) examine the impact of storms on fertility and find that mild (strong) storms have a statistically observable positive (negative) effect on human fertility; while Worthington and Valadkhani (2004) trace the impact of disasters on stock markets using event-study methodology and find mixed effects.

Heger et al. (2008) focus on all the Caribbean islands, and find that, as growth collapses in the aftermath of climatic events, the fiscal and trade deficits both deteriorate and the island economies of the region find it difficult to rebound. Yang (2008) and Bluedorn (2005) investigate the evolution of capital flows following disasters, and both conclude that disasters generate some inflows (mostly international aid; but also other types of flows like remittances).

5. Case studies of disaster impacts

Several research projects have examined the economic impact of specific disaster events – recent examples are the 1995 Kobe earthquake in Japan (Horwich, 2000), the 1999 earthquake in Turkey (Selcuk and Yeldan, 2001), and hurricane Katrina in 2005 (Vigdor, 2008); most of these are descriptive, though some also construct calibrated models that simulate the dynamics of the economy after it is hit by the disaster and are therefore able to tentatively evaluate various policy responses.

These analyses were typically written not so long after the event and thus report mostly on its short-term impact or the causes for some of the damages. If they do project or estimate long run impacts, they are unable to separate this impact from other trends and shocks that would have occurred regardless of the disaster event. The case of Hurricane Katrina demonstrates this problem. Vigdor (2008), in a carefully constructed descriptive investigation of Katrina's impact on New Orleans, documents significant population declines. However, as he readily acknowledges, it is impossible to separate these declines from a general declining trend in the city's population that long predates Katrina (though which Katrina clearly accelerated).

Coffman and Noy (2009) investigate the long-term impact of a 1992 hurricane on the economy of a Hawaiian island. In this case, the long horizon available, the unexpectedness of the event, and the existence of an ideal control group subjected to almost identical conditions but not the hurricane itself, enables them to argue that in spite of massive transfers, it took nearly 7 years for the island's economy to return to its pre-hurricane per capita income level. The hurricane also resulted in an out-migration of residents from which the island's population has not fully recovered; the island permanently 'lost' about 15% of its population as a result of the hurricane (very few deaths were associated with the storm).

Numerous other papers have examined specific disaster cases; typically focusing on a specific question. The immigration patterns generated by a strong hurricane in El Salvador are examined by Halliday (2006); Vos et al. (1999) study Ecuador and its vulnerability to the El Niño weather; Pettersen et al. (2005) study the shortcomings of the risk management strategies in Chile, El Salvador and Peru; and Cardenas (2008) proposes an innovative financing scheme for catastrophic risk using Honduran circumstances as an example.

6. Policies and disasters

Perrow (2007), in a recent book on reducing catastrophic vulnerabilities in the U.S., argues that public policy should focus on the need to 'shrink' the targets: Less population concentrated in vulnerable (especially coastal) areas, and less concentration of utilities and other infrastructure in disaster prone locations. This advice stems from the awareness that more *ex-post* assistance to damaged communities generates a 'Samaritan's dilemma' – i.e., an increase in risk taking and a reluctance to purchase insurance when taking into account the help that is likely to be provided should a disaster strike.[14] However, besides these *ex-ante* 'shrink-the-target' policies, many other *ex-ante* and *ex-post* policies that can alleviate or worsen the economic impact of disasters will necessarily be weighed before and after any large event.

[14] This is similar to the 'moral-hazard' problem common in insurance markets. Raschky and Weck-Hannemann (2007) define it as 'charity hazard.'

Besides policies that can reduce the initial disaster damage, policies that can reduce the longer-term economic damage that disasters can wreak should also be contemplated. We have already observed that large disasters typically lead to reduced production and incomes, even if the exact distribution of these effects and their causes are not yet clear. Yet, as Freeman et al. (2003) observe, some of the other likely macroeconomic impacts of disasters may be a deteriorating trade balance, a downward pressure on the exchange rate, and an upward pressure on prices. How to deal with these likely dynamics are policy questions that also need to be asked.

6.1 Ex-ante insurance vs. ex-post disaster financing

Kunreuther and Pauly (2009) survey some of the problems associated with *ex-ante* insurance coverage for large natural events: uncertainty with regards to the magnitude of potential loses, highly correlated risk among the insured, moral hazard that leads to excessive risk taking by the insured, and an adverse selection of insured parties caused by imperfect information. Their work also distinguishes between unknown disasters (those for which the likelihood and the distribution of probable magnitudes are at least partially known) and the unknowable (those for which no information is available). Even though natural disasters are typically not unknowable, these problems still clearly lead to under-insurance. In all recent disasters, even in ones that happened in heavily insured countries like the U.S., only a relatively small portion of actual damages was insured. For example, hurricane Katrina led to insurance claims totaling $46.3 billion; while the estimated damage of the storm was $158.2 billion.[15]

Insurance for the public sector, in order to secure the availability of reconstruction expenditures, is also an important policy question. There is broad consensus on the need to design fiscal management policies to resist the stress caused by the occurrence of disasters. Freeman et al. (2003) consider ways to create the necessary fiscal space to deal with catastrophic risk. Among various alternatives, they advocate treating natural disasters as a contingent liability for the national government (although they are skeptical about this suggestion's practical feasibility, particularly in low-income countries). A more substantive initiative would be to implement an annual budgetary allocation to provide for natural disaster expenditure when needed. Mexico's FONDEN (Fondo Nacional de Desastres Naturales) provides this kind of fiscal provisioning against the risk of natural disasters. But these measures, while prudent, amount to forms of self-insurance, which may be very costly in the case of an economy with substantial borrowing costs.

Borensztein et al. (2009) argue that, in the case of developing countries exposed to large natural disasters, insurance—or debt contracts with insurance-like features—provides an attractive alternative to self-insurance.[16] As an example, they examine the vulnerability of Belize's public finance to the occurrence of hurricanes and the potential impact of insurance

[15] Katrina insurance claim data is from Kunreuther and Pauly (2009), while the figure for total damages is taken from EM-DAT. The Congressional Budget Office estimates $70-130 billion as direct damages (excluding the cost of clean-up and repairs) for hurricanes Katrina and Rita.

[16] In the case of temporary shocks, whose effect is reversed over time, and where countries do not face borrowing constraints in global markets during periods of economic distress, a strategy of borrowing and saving, such as those applied by stabilization funds, could be fully appropriate. Even in this case, there are caveats, as it all depends on the price charged for the market insurance (or whether that market exists). Ehrlich and Becker (1972) show that self-insurance and market insurance are substitutes, and may coexist in equilibrium. See also Borensztein et al (2005), and Hofman and Brukkof (2006).

instruments in reducing that vulnerability. Through numerical simulations they show that catastrophic risk insurance significantly improves Belize's debt sustainability.

Implementing disaster insurance in developing countries, however, faces three types of obstacles: paucity of markets, political resistance and inadequate institutional framework. For a number of reasons, markets have traditionally been insufficiently developed or simply nonexistent (more on this below). More recently, however, advances such as the development of parametric insurance policies have expanded the availability of coverage for countries and households (see Cardenas, 2008).[17]

Political reluctance to engage in insurance purchase derives from the fact that there is little benefit for a political leadership with a short horizon from entering insurance contracts. Insurance involves costs today and a possible payoff in the undetermined future, when the government may have already changed hands. In addition to these incentive problems, disasters are widely considered as 'divine acts' (or natural phenomena) and politicians are typically not blamed for their occurrence. These politicians and policy-makers, therefore, face very weak incentives to take relatively complex measures, such as purchase market insurance, to offset some of the costs; Healy and Malhotra (2009) present evidence to support these conjectures even for the transparent and fairly stable political system of the U.S. However, since governments are typically held accountable to the disaster response they present, they have strong incentives to massively invest in *ex-post* assistance.

[17] Instead of basing payments on an estimate of the damage suffered, parametric insurance contracts establish the payout as a function of the occurrence or intensity of certain natural phenomenon, as determined by a specialized agency such as the U.S. National Hurricane Center or the U.S. National Earthquake Information Center. In this way, the transaction costs and uncertainty associated with insurance payments are considerably reduced. There is no need to verify and estimate damages, and no potential disagreement or litigation about the payouts. Moreover, the country has immediate access to the resources when the disaster takes place.

Inadequate institutional framework relates to low government policymaking capabilities in developing countries. In particular, Pettersen et al. (2005) raise doubts about the value of implementing sophisticated risk management instruments in a weak institutional environment with opaque asset management practices in the public sector, poor risk statistics and inadequate systems for loss valuation and claim settlements. In their view, improved capacity for risk retention at the country level –to be achieved through sound fiscal management—is more important than the need to apply new instruments for risk transfer.

Of the three obstacles that deter the development of catastrophic risk insurance market, the one related to market unavailability has been the most studied. The consensus is that governments in countries that are vulnerable to natural disasters appear to have only a limited set of options available to insure public finances against those risks, although progress is slowly being made. Hofman and Brukoff (2006), Cardenas (2008), Andersen (2002, 2005 and 2007) and Miller and Keipi (2005) survey some recent initiatives in this regard. The risk profile of catastrophe insurance claims differs from other insurance products. A company providing car insurance can easily diversify if it has many clients, since the volume of claims would then be highly predictable. In contrast, natural disasters are low-probability events that can cause extremely large losses when they occur, and are thus not easily diversifiable in the same way as car insurance. This low level of diversification increases the cost of insurance and makes prices very volatile, fluctuating sharply every time that there is a major catastrophic event that depletes reserves. Primary insurers need to transfer a considerable share of their catastrophe exposure to large reinsurers. The increased reliance on reinsurers increases the cost of primary insurance, reducing its attractiveness and scope.[18]

Private capital markets offer some complementary alternatives that may increase the availability of financing options as they continue to develop. The first capital market instrument linked to catastrophe risk ("cat bonds") was introduced in 1994 as a means for reinsurers to transfer some of its own risks to capital markets. Since then, their success has prompted governments and international institutions to explore their use as a mean of shielding governmental budgets from the impact of natural disasters.[19] A catastrophe bond is a tradable instrument that facilitates the transfer of the risk of a catastrophic event to capital markets. A typical structure is one in which the investors purchase a safe bond, such as a U.S. Treasury bond, for the desired amount of coverage and deposit it with a Special Purpose Vehicle (SPV) institution, which is legally distinct from the parties. The investors collect the interest on the bond plus the insurance premium that is paid by the insured party while the disaster does not occur. If the disaster strikes, however, their claim is extinguished and the SPV sells the bond and transfers the funds to the insured. In May 2006 and again in October 2009, the Mexican government obtained earthquake and hurricane insurance by means of cat bonds and a direct purchase of coverage from international reinsurers.

While these are encouraging developments, the private catastrophic risk market is still in its infancy. And even if the supply-side of risk financing instruments becomes fully developed, important questions remain unanswered. For example: What is the optimal level of insurance

[18] In recent years, reinsurers themselves have also begun to rely more on capital markets to reduce their own exposure.
[19] See Andersen (2002, 2005 and 2007)

that countries should purchase given the cost of insurance, the menu of alternative financing options (self-insurance, ex-post debt accumulation, foreign aid, etc.) and country characteristics (access to external credit, macroeconomic environment, institutional quality, etc.)?; What is the appropriate institutional set-up that ensures the well functioning of insurance schemes while minimizing moral hazard and adverse selection? What is the appropriate role of the government vis-à-vis the private sector in catastrophic insurance markets? These are still open questions that warrant further analysis.

6.2 Monetary and Exchange Policy

There has also been very little research on the monetary aspects of disaster dynamics. As far as we are aware, even elementary questions as, for example, what is the inflationary impact of a large disaster and the aid surge in its aftermath, have not been carefully examined. Open-economy questions, such as the impact of disasters on exchange rates (real or nominal) or the terms of trade have also not been examined empirically or analytically.

Keen and Pakko (2007) construct a dynamic stochastic general equilibrium model calibrated for the U.S. economy and the impact of Katrina, and evaluate the optimal response of monetary policy to a Katrina-like shock. They find, intriguingly given public discussion and market perceptions at the time, that optimal monetary policy design should involve raising interest rates following a large disaster. They show that this result holds for both a Taylor-rule setting of interest rates, for optimal policy setting that replicates the efficient markets solution, and also remains if the model includes nominal rigidities in both prices and wages. Keen and

Pakko (2007) argue that this result arises because the anti-inflation motivation of the contractionary policy will dominate any desire to temporarily expand output.

In possibly the only empirical paper on exchange rates and disasters, Ramcharan (2007) examines exchange rate policy and its affect on the damage disasters inflict. He estimates a variant of equation (5), while controlling for the exchange rate regime and its interaction with the disasters. He finds consistent evidence that flexible exchange rate regimes provide a cushion that ameliorates the disaster's negative impact on growth. All these policy questions, however, should only be evaluated while also accounting for the future likelihood and potential magnitude of disaster events.

7. Climate Change and Natural Disasters

There is a robust scientific consensus that human activity, particularly the burning of fossil fuels, is drastically altering the globe's climate. The Intergovernmental Panel on Climate Change (IPCC) [20] states that: "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level" (IPCC, 2007). By 2100, average global surface warming is projected to increase by between 1.8 degrees Celsius to 4 degrees Celsius depending on the success of emissions mitigation strategies; though some level of warming is expected regardless, even if all emissions were stopped today (IPCC, 2007).

The 2007 IPCC report also predicts that sea levels will rise between 0.18 and 0.59 meters by 2100. More recent predictions of global sea level rise are considerably more drastic,

[20] The IPCC is a scientific body established by the World Meteorological Organization and the United Nations Environment Program to assess the risks and impacts of human-induced climate change.

however, as more information on glacial melting has become available. Rahmstorf (2007), for example, predicts a sea level rise of 0.5-1.4 meters by 2100**.** In addition, the absorption of carbon in the ocean has lead to increased acidity and has resulted in wide-spread calcification of coral reefs. This coral bleaching leads to destruction of reef systems that protect coastal areas from storm surges.

There is limited understanding on how global warming will affect storm activity. One of the necessary conditions for hurricane formation is ocean water temperature greater than 26°C to a depth of about fifty meters. Several studies posit that, as global sea surface temperatures rise, there will either be more hurricanes, more intense hurricanes or the hurricanes range will increase to the north and south of the current 'hurricane belt' (e.g., Webster et al., 2005).

The science, however, is not conclusive. IPCC 2007 states that: "There is observational evidence of an increase in intense tropical cyclone activity in the North Atlantic since about 1970, with limited evidence of increases elsewhere. There is no clear trend in the annual numbers of tropical cyclones. It is difficult to ascertain longer-term trends in cyclone activity, particularly prior to 1970" (IPCC, 2007). Elsner et al. (2008) suggest that warming temperatures allow for already strong storms to get even stronger. This suggests that, while there may not necessarily be an increased number of storms, there will be an increased occurrence of strong storms. In general, however, the debate over how global warming will affect storms in both potency and incidence continues.[21] In any case, the combination of sea level rise and deteriorated coral reef ecosystems will make coastal areas considerably more vulnerable to storms, regardless of whether they will indeed be more frequent or more intense.

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[21] Doubts have also been raised over the quality of global databases on storm activity (e.g., Landsea et al., 2006).

The impact of global climate change on the incidence of other types of natural disasters is even less known. The incidence of geophyisical disasters is unlikely to be affected, but there is some, mostly historical, evidence that draughts and floods will become more common and more severe (e.g., Fagan, 2008).

Hallegatte et al. (2007), construct a dynamic general equilibrium model that also includes the possibility of dis-equlibria during transient periods, and which specifically includes the occurrence of extreme weather-related events. As they point out, most estimates of the future effects of climate change examine the average likely change and stipulate from that on the smooth growth transition path for economic activity. However, as we observed above, the probability distribution of extreme events is also likely to change. Using their calibrated model, they calculate the *economic amplification ratio* (the multiplier from direct capital destruction to indirect economic losses). They show that the future changes in the distribution of disasters have the potential of generating large amplification ratios and thus very large economic affects if disaster magnitudes are beyond a certain threshold. Very large disasters, or a sequence of disaster events, can have the potential of overwhelming the reconstruction capacity of a country and leaving it stuck in a poverty trap.

8. Conclusions and remaining Questions

The economics of natural disasters are important, and in order to facilitate further necessary research on this topic, we summarized the state of this literature. However, we believe that large gaps in this literature remain. The EM-DAT, the only internationally comparable and available data on disasters, collects only limited information on conceivably too many events.[22] A more detailed accounting of the physical destruction wrought by large disasters and of their human toll may prove to be very useful. We especially would like to be able to distinguish between residential damage, crop devastation, infrastructure damage, and destruction of manufacturing facilities to enable examination of many of the questions that remain unanswered.

Primarily, while the literature we reviewed examines the short- and long-run effects of disasters, and provides detailed, if inconclusive, accounting of output dynamics, it does not provide any description of the channels through which the disasters cause these output effects. An understanding of the channels of causality, in both the short- and the long-run, will surely enable more informed *ex-post* policymaking and even *ex-ante* preparation and mitigation.

For example, we presented some provisional evidence that the extent of adverse impact is related to the ability to mobilize significant funding for reconstruction. We have also shown that poorer countries are likely to suffer more from future disasters, but these countries are also unlikely to be able to adopt the counter-cyclical fiscal policies that can pay for reconstruction.[23] This constraint will make the disaster's adverse consequences more severe in poorer developing countries. A better targeted reconstruction that is informed by the identified channels of transmission can potentially alleviate some of these resource constraints.

A further significant lacuna in the current state of our knowledge is the absence of any agreement regarding the long-run effects of these disasters. Whether these disagreements

[22] Since the threshold used to determine what constitutes a disaster is quite lenient, the dataset contains limited information on a large variety of events.

[23] Ilzetzki and Végh (2008) document counter-cyclical fiscal policy in richer countries and pro-cyclical policy in the developing world, probably driven by public credit constraints.

have any substantial real relevance to policy decisions can only be assessed when the channels of transmission and propagation for any long-run effects become more evident.

We have not reviewed the micro-development literature that has been examining the ways in which households (typically rural households) deal with sudden disaster events (e.g., Townsend, 1994; Udry, 1994, and Dercon, 2004). Whether these shed light on the channels of transmission is a possibility that needs to be further explored. We have also not reviewed the literature on aid allocations following disasters and its impact. This literature was recently surveyed by Strömberg (2007).

The original exogenous aspect of the natural trigger (e.g., the storm or the earthquake) can also enable economists to examine more closely the importance of rare but large deviations from trend for various aspects of economic dynamics. This may be of special interest given the increasing realization among macroeconomists that one needs to model and carefully investigate not only the smooth transitions and cycles of the macro-economy but also the rare but extreme volatility events that have profound implications for the smoother 'normal' path.[24] Several recent papers, in particular Barro (2006 and 2009), Pindyck and Wang (2009) and Gabaix (2008), are already exploring many of these possibilities, but not necessarily within the context of natural disasters, their occurrence, and their impacts.

[24] See Krugman (2009) for a scathing attack on the failure of the profession to weight carefully the possibility of large abnormal events.

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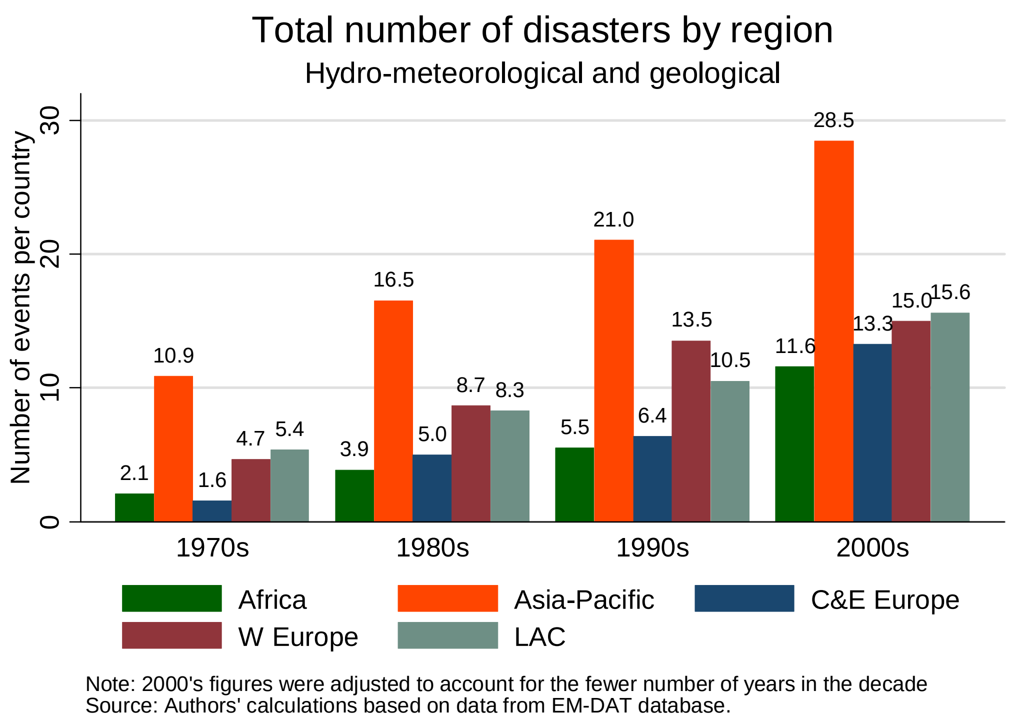


Figure 1: Incidence of natural disasters by region, 1970-2008

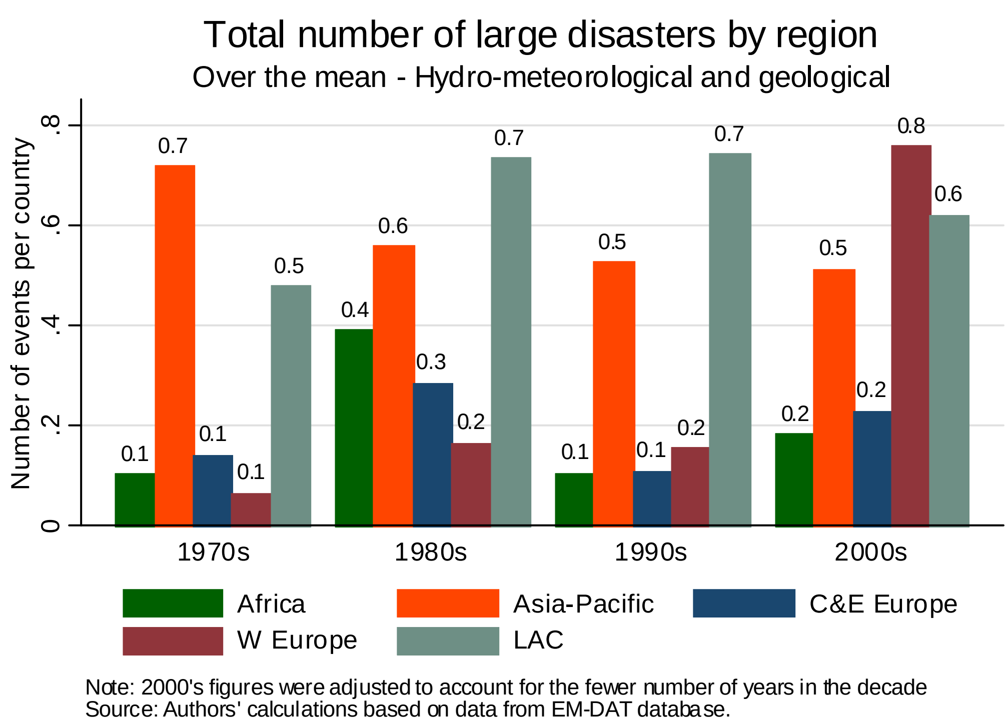


Figure 2: Incidence of “large” natural disasters by region, 1970-2008

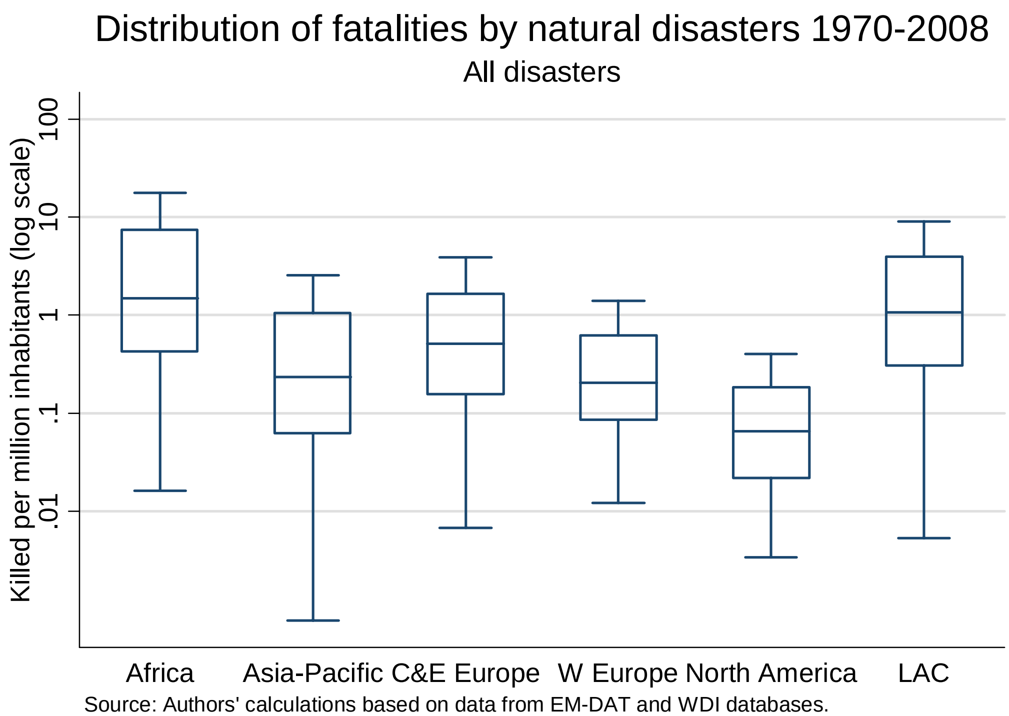


Figure 3: Distribution of fatalities by regions, 1970-2208

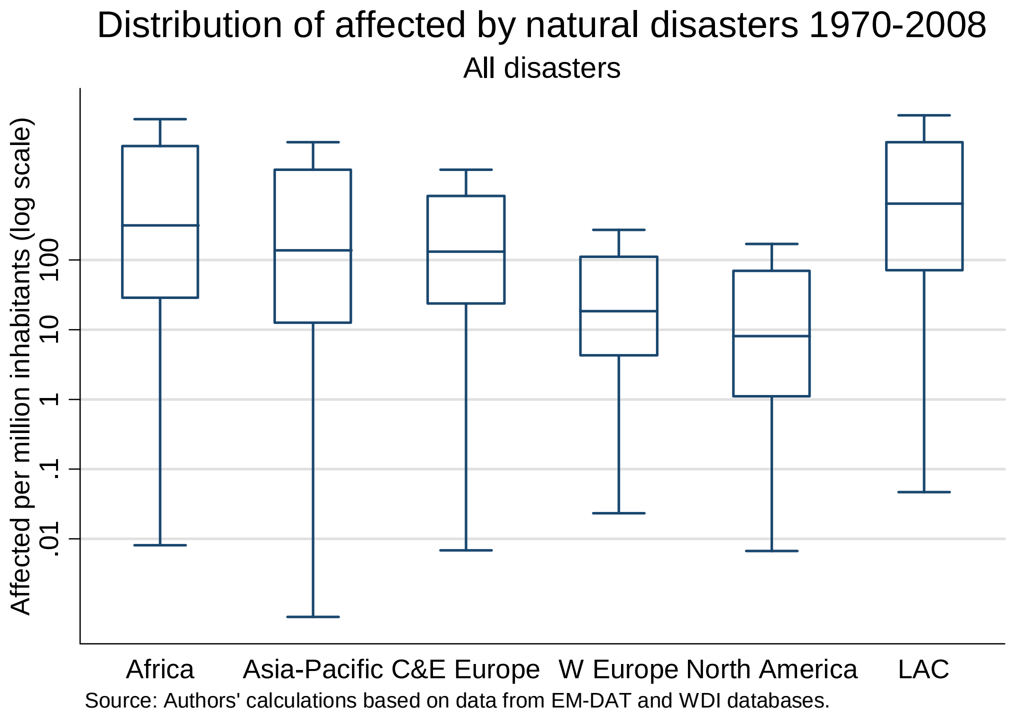


Figure 4: Distribution of affected by regions, 1970-2008.

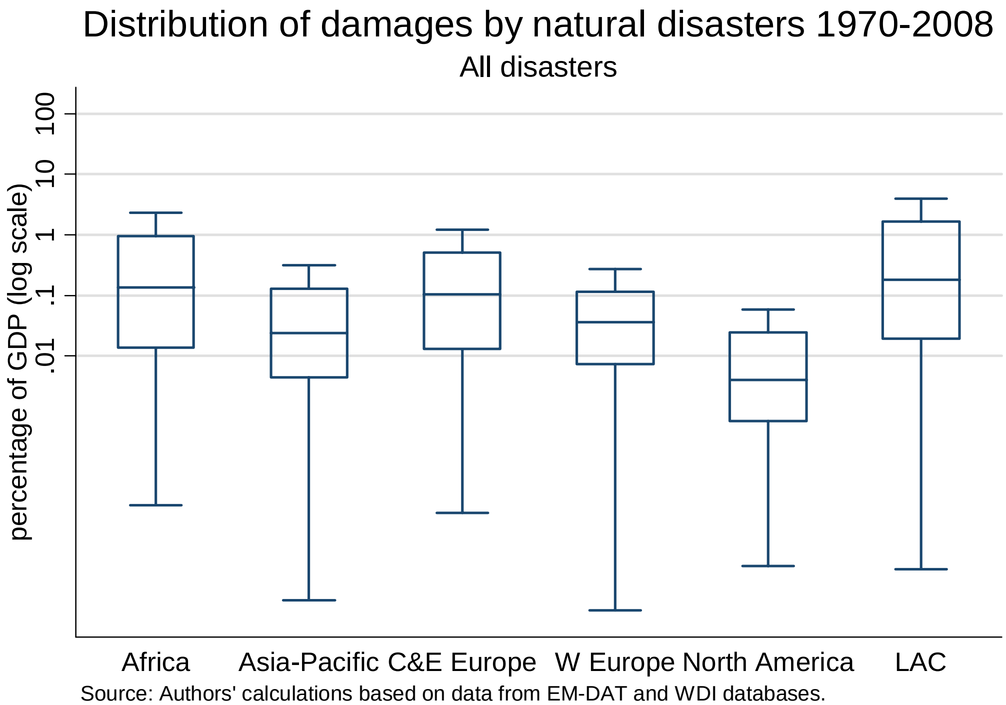
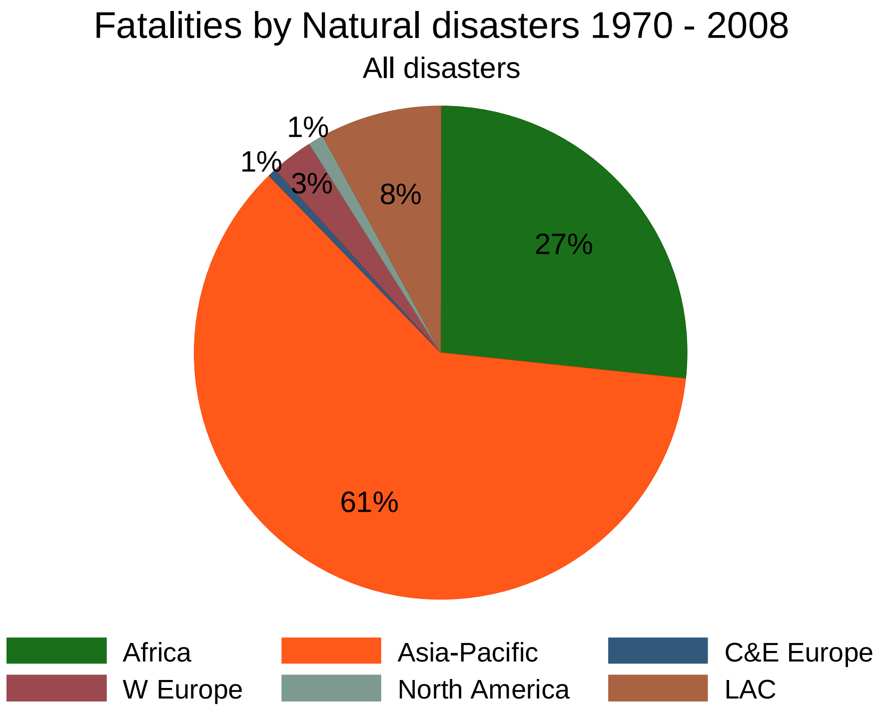


Figure 5: Distribution of direct economic damages by region, 1970-2008.



Source: Authors' calculations based on data from EM-DAT database.

Figure 6: Concentration of fatalities by region, 1970-2008.

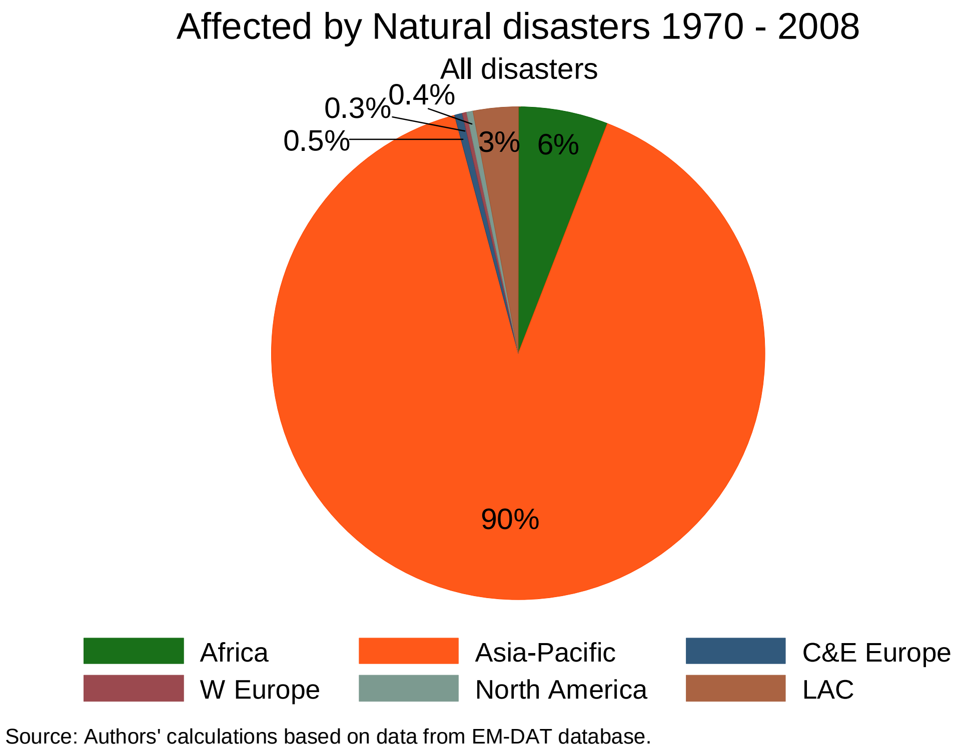


Figure 7: Concentration of affected by region, 1970-2008.

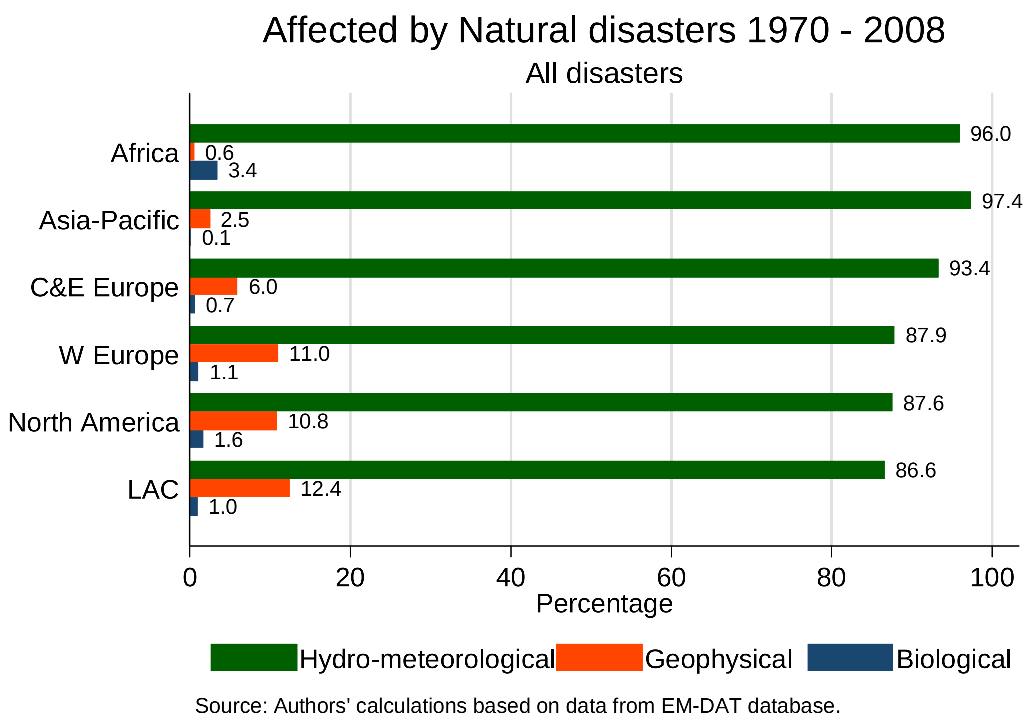
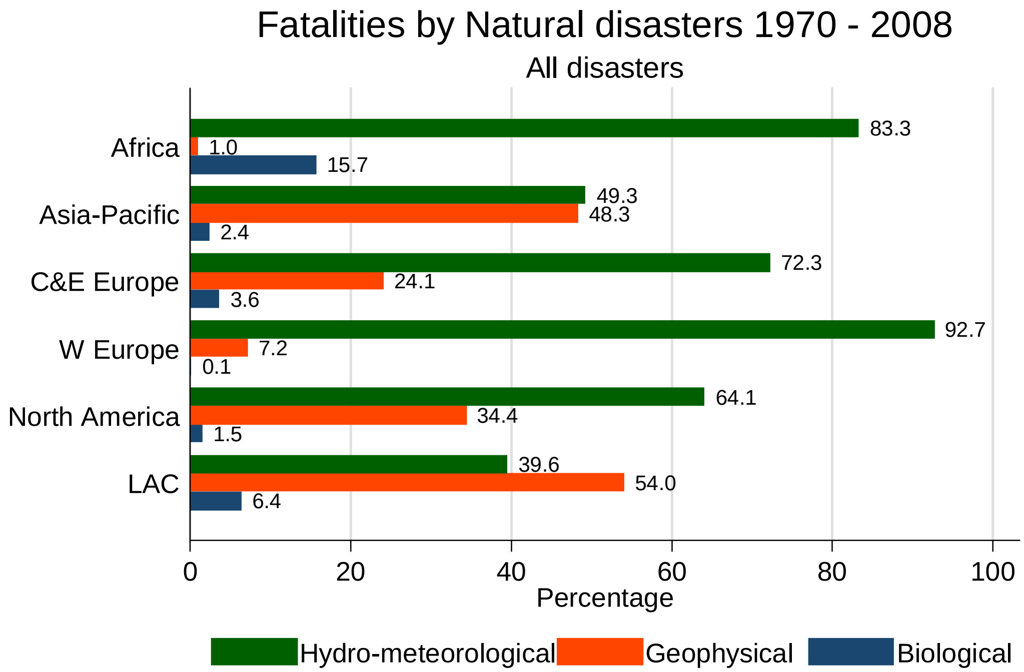


Figure 8: The causes of affected by type of event, 1970-2008.



Source: Authors' calculations based on data from EM-DAT database.

Figure 9: The causes of fatalities by type of event, 1970-2008.

Table 1: Short-Run Disaster Effects on GDP

Paper	Conclusion	Estimated effect [1]
Albala-Bertrand (1993)	Disasters have a neutral or positive effect on economic growth.	Difference between averages: 0.4% [2]
Raddatz (2007)	Climatic and humanitarian events reduce real per-capita GDP. Geological events do not have a significant impact.	Climatic: about -2% of GDP per capita [3]
		Humanitarian: about -4% of GDP per capita
		Geological. Not significant
Strobl (2009)	Hurricanes have a negative impact on county growth, although counties show a smaller recovery the following year.	Immediate impact: -0.8% of per capita income [4]
		Impact one year after: 0.2% of per capita income
Loayza et al. (2009)	Disasters have differential effects on economic growth. They are more adverse for developing countries.	Droughts: -0.606% of GDP [5]
		Floods: 0.996% of GDP
		Earthquakes and storms : Not significant
Noy (2009)	Disasters have a negative impact on economic growth when measured by the property damaged, but not when measured by population. Effect is larger for developing and smaller economies.	For OECD countries: short run effect: 1.33% of GDP; Cumulative effect 1.99% of GDP [6]
		For developing countries: short run effect: -9.7% of GDP; cumulative effect -11.7% of GDP
Rodriguez-Oreggia et al. (2009)	There is a significant impact from natural disasters on reducing the Human Development Index (HDI) and also on increasing poverty levels.	HDI: going back about 2 years of development [7]
		Severe poverty: 0.036%
		Capacities poverty: 0.03%
		Assets poverty: 0.015%
Leiter et al. (2009)	Companies in regions hit by floods show higher growth of total assets and employment than firms in unaffected regions. The positive effect prevails for companies with larger shares of intangible assets.	Marginal effect of a flood on total assets (3rd quartile of share of intangible assets): 2.6% of total assets [8]
		Marginal effect of a flood on employment (3rd quartile of share of intangible assets): 4.7% of employment
Mechler (2009)	Losses caused by natural disasters do not explain changes in consumption. However, adjusting savings for disaster effects helps in better explaining post-disaster changes in consumption, especially for low-income countries.	Not significant coefficients [9]
Hochrainer (2009)	Natural disasters have a negative impact on GDP.	-0.5% of GDP after the first year, -4% of GDP after 5 years [10]

(1) A positive (negative) value means an increase (decrease) of the dependent variable. Estimated effect column only reports statistically significant estimates.
(2) Table 3.6 in paper.
(3) Figure 3, panels D, E and F in paper.
(4) Table 3, column 6 in paper.
(5) Effects for developing countries. Chart 2 column 1 in paper.
(6) Table 5, rows 1 and 2 in paper.
(7) Table 2, column 9 in paper.
(8) Table 8, columns 8.1 and 8.2 in paper.
(9) Table 5 in paper.
(10) Table 3, columns 2 and 6 in paper.

Table 2: Long-run growth effects

Paper	Conclusion	Estimated effect [1]
Skidmore and Toya (2002)	Climatic events have a positive relationship with long run growth. Geological events has a negative or neutral effect	Climatic Events: 0.42% of GDP [2]
		Geological Events: -0.32% of GDP
Noy and Nualsri (2007)	A shock to the killed variable results in a decreased growth rate while a shock to the damages variable does not seem to have much statistically observable effect on long run growth.	Estimated coefficient, killed as ratio of population: -6.58 [3]
		Estimated coefficient, damages as ratio of GDP: Not significant
Cuaresma et al. (2008)	Natural disasters are negatively correlated to the technological transfer between developing and developed countries.	Natural disaster frequency coefficient: -0.69 [4]
		Natural disaster loss coefficient: -0.28 [5]
Raddatz (2009)	Climatic disasters have a negative impact on per capita GDP. Geological events do not have a significant impact. This effect is greater for smaller economies	Climatic. -0.6% of GDP per capita [6]
		Geological. Not significant

(1) A positive (negative) value means an increase (decrease) of the dependent variable. Estimated effect column only reports statistically significant estimates.
(2) Effects calculated by authors assuming a shock of one standard deviation reported in the paper in table C1.(2) and impact from table 4, column 2.
(3) Table 2, columns 2 and 3 in paper.
(4) Table 2, column 1 in paper.
(5) Table 3, column 1 in paper.
(6) Figure 4 in paper.